J. Physiol. (1953) 122, 399–402

A METHOD FOR THE CALCULATION OF METABOLIC WATER

By S. D. MORRISON

From the Institute of Physiology, University of Glasgow

(*Received* 18 *May* 1953)

In investigations of the water exchange and water balance of animals it is frequently necessary to estimate the water of oxidation or metabolic water. Where water intake is being measured specifically it is essential to take this metabolic component into account along with food moisture, as these can greatly modify the interpretation to be placed on variations in purely fluid intake, as for example, in studies of the effect of dietary composition on water intake. Where water balance is estimated directly, a measure of the metabolic water is essential, and even when water balance is estimated indirectly from the dry-matter exchange, by Peters's equation (Peters, Kydd & Lavietes, 1933), it is of great value to have, also, a measure of the absolute quantity of water exchanged.

The customary method of estimating metabolic water from respiratory metabolism data is cumbrous, entailing the partition of the components of combustion, and the separate calculation of the metabolic water produced from the combustion of protein, fat and carbohydrate. The alternative method of applying standard values for metabolic water to each of the dietary proximate principles, e.g. 0·41, 1·07 and 0·60 g water for protein, fat and carbohydrate respectively (Brody, 1945), entails a precise knowledge of the composition of the diet, and is, in any case, inaccurate unless the composition and water equivalent of the faecal loss be also known. In a long series of 24 hr metabolic studies of the rat I found it necessary to calculate the metabolic water for each day. The following method, which greatly facilitates this calculation, was therefore derived.

Weir (1949) derived an equation for the calculation of metabolic rate directly from the measured oxygen consumption, carbon dioxide production and urinary nitrogen production. A similar equation can be derived, in like fashion, for the calculation of metabolic water.

The respiratory constants used here for the metabolism of protein differ slightly from those customarily used. They have been recalculated directly from Loewy's (1911) data. An error in the protein R.Q. has been eliminated which was unfortunately introduced by Lusk (1928) who applied a volumetric correction to gravimetric data.

TABLE 1. Symbols and numerical values used in deriving equations

	Carbohydrate	Protein	Fat
R.Q.	1·0	0·796*	0·708†
kcal/l. O_2	5·037‡	4·463*	4·686§
g H_2O/l. O_2	0·669‡	0·410*	0·532†
Vol. O_2 metabolizing	x	y	z

* Calculated from the data of Loewy (1911). The weight of water produced was calculated from the metabolized protein after removal of the faecal loss, and taking account of the nitrogenous component of the urine.

† Calculated on the basis of complete combustion of a hypothetical mixture of equal parts of tripalmitin and triolein.

‡ Calculated on the basis of complete combustion of a 90:10 mixture of polysaccharide and disaccharide.

§ Zuntz & Schumberg (1901).

From the terms in Table 1 the following basic equations can be constructed:

$$\text{litres } O_2 \text{ consumed} = V = x + y + z, \tag{1}$$

$$\text{litres } CO_2 \text{ produced} = RV = x + 0{\cdot}796y + 0{\cdot}708z, \tag{2}$$

$$\text{g water produced} = W = 0{\cdot}669x + 0{\cdot}410y + 0{\cdot}532z. \tag{3}$$

Solution of these simultaneous equations gives

$$W = 0{\cdot}1998V + 0{\cdot}4692RV - 0{\cdot}1633y. \tag{4}$$

Using the factor of 5·940 l. oxygen/g urinary nitrogen, derived from Loewy's (1911) data, the last term of equation (4) can be expressed as $0{\cdot}1633 \times 5{\cdot}940 \times$ g urinary N. This gives a final form for the water equation of

$$\text{Metabolic water formed (g)} = 0{\cdot}1998 \times \text{litres } O_2 \text{ consumed} + 0{\cdot}4692 \times \text{litres } CO_2 \text{ produced} - 0{\cdot}9700 \times \text{g urinary N}. \tag{5}$$

As a measure of the respiratory quotient is normally required in investigations yielding the data necessary to apply this equation, the above is a convenient form of the equation. If necessary it can, of course, be converted to express either or both of the gaseous components in terms of weight. For this conversion the constants in the terms in oxygen and carbon dioxide would be substituted by 0·1398 and 0·2373 respectively.

The true metabolic water, as given by equation (5), cannot be derived without precise measurement of the total daily oxygen consumption and carbon dioxide and urinary nitrogen loss. In studies on human metabolism it is very rarely that the component terms of the above equation are available, or are obtainable with sufficient accuracy to justify the use of equation (5). This is also frequently true of investigations of the water balance of animals, when data for only relatively short 'basal' periods may be known. It may be useful, therefore, to consider a form of the equation expressed in more usually measured terms. The following calculations do not eliminate the necessity for the above long-period measurements if accurate estimation of metabolic water is to be obtained, but merely substitute some average values to give convenient working equations.

The equation for total energy production, corresponding to (5) above, is

$$\text{Total kcal} = 3{\cdot}840 \times \text{litres } O_2 \text{ consumed} + 1{\cdot}195 \times \text{litres } CO_2 \text{ produced} - 1{\cdot}950 \times \text{g urinary N}. \quad (6)$$

The constants in this equation differ slightly from those given by Weir (1949), as the basic terms used in its calculation correspond to those used above for the calculation of metabolic water.

Solution of equations (5) and (6), with elimination of the term in oxygen volume, gives the equation

$$W = [K(0{\cdot}1998 + 0{\cdot}4692R) - N(3{\cdot}3352 + 0{\cdot}2443R)]/(3{\cdot}840 + 1{\cdot}195R), \quad (7)$$

where W, K, N and R are, respectively, total metabolic water in g, total energy production in kcal, total urinary nitrogen in g and total R.Q.

If the energy derived from protein is assumed to be one-eighth of the total energy production, equation (7) can be reduced to:

$$W = K(0{\cdot}1832 + 0{\cdot}4680R)/(3{\cdot}840 + 1{\cdot}195R). \quad (8)$$

For a given R.Q. the error introduced into the estimate of total metabolic water by ignoring the protein correction is about 0·23 % for each 1 % of total energy derived from protein.

The total energy production, K, can be derived from the respiratory exchange, as also can the total R.Q. Failing this, the energy can be estimated from the dietary intake, and a value can be assumed for the R.Q. Thus, assuming a value of 0·9 for the R.Q., equation (8) can be further reduced to

$$W = 0{\cdot}123K. \quad (9)$$

It is to be noted, however, that the estimate of metabolic water is more sensitive to variation in R.Q. An error of 1 % in the assessment of average total R.Q. produces an error of 0·6 % in the water estimate in the same direction.

All the equations presented above are based on the use of standard values to define the oxidative degradation of dietary components. If the true values depart greatly from those used here, the constants given in equations (5) and (6) will be in error. The energy equation is most sensitive to changes in type of dietary fat, as fats show a wide range of heats of combustion; the water equation is most sensitive to changes in type of carbohydrate, polysaccharides producing only five-sixths the amount of water, per litre of oxygen, produced by monosaccharides on oxidation. Any such deviation is unlikely to have a serious effect, however, unless the diet is very unusual. In animal experiments, if the constants of the particular diet used can be accurately defined, it would be as well to recalculate equations (5) and (6).

All the equations hold even when body tissue is being deposited or oxidized, the differences between the composition of the dietary components and the body tissue components having a negligible effect. The equations do not, of course, hold in metabolic disturbances affecting the end-products of metabolism, such as ketosis. In the case of equation (9), however, deposition or oxidation of body tissue may have a significant effect on the total R.Q., and if body weight is being gained or lost it might be advisable to increase or decrease, respectively, the estimate of R.Q. substituted in equation (8). It must be remembered that equation (9) is at best an approximation, which is simpler to calculate than the usual approximate method and, on an average diet, is unlikely to be in error to the extent of more than $\pm 5\%$.

SUMMARY

1. An equation is derived for the calculation of metabolic water from the components of the respiratory exchange.

2. Further equations are presented for the estimation of metabolic water from the total energy production.

3. The validity of these equations under varying dietary conditions is discussed.

REFERENCES

Brody, S. (1945). *Bioenergetics and Growth*, p. 36. New York: Reinhold.

Loewy, A. (1911). Der respiratorische und der Gesamtumsatz. In Oppenheimer, C., *Handbuch der Biochemie des Menschen und der Tiere*. Jena: Gustav Fischer.

Lusk, G. (1928). *The Elements of the Science of Nutrition*, 4th ed. pp. 64, 68. Philadelphia: W. B. Saunders.

Peters, J. P., Kydd, D. M. & Lavietes, P. H. (1933). A note on the calculation of water exchange. *J. clin. Invest.* **12**, 689–694.

Weir, J. B. de V. (1949). New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol.* **109**, 1–9.

Zuntz, N. & Schumberg, H. (1901). *Studien zu einer Physiologie des Marsches*, p. 260. Berlin: Hirschwald.